The Effect of Fatigue on Lower Extremity Biomechanics and Balance in Anterior Cruciate Ligament Reconstructed Individuals

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ABSTRACT

CHRISTINE M. GILSDORF: The Effect of Fatigue on Lower Extremity Biomechanics and Balance between ACLR and Healthy Individuals
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The purpose of this study was to investigate the effects of fatigue on balance in females with ACLR. A total of 14 female ACLR participants (age= 19.64±1.5 years; height = 163.52±6.18cm; weight = 62.6±13.97kg) were used in this study. All participants completed a balance task, before and again after a fatigue protocol that consisted of a stationary squatting task. There was a significant difference in COP velocity and COP sway path between the pre-fatigue and post-fatigue conditions as COP velocity and COP sway path significantly increased from pre-fatigue to post-fatigue. Results indicate that female ACLR individuals have significantly greater COP velocity and COP area after fatigue.

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CHAPTER I

INTRODUCTION

Injury to the anterior cruciate ligament (ACL) has long been an important topic among a wide range of sports, spanning all the way from professional sports like American football to youth sports. ACL injury in athletes is greatly feared as it represents an invasive surgery, arduous rehabilitation and can possibly end an athlete's career. Unfortunately, injury to the ACL is a common traumatic knee injury. In a 10 year study conducted by Majewski et al, the ACL was implicated in 45.4% of knee injuries (Majewski, Susanne et al. 2006). Even more disturbing, individuals that had previous history of ACLR are 15 times at greater risk to incur a second injury as compared to a healthy population (Paterno, Rauh et al. 2012). This makes screening these individuals for return to play of particular concern for clinicians.

About 70% of ACL injuries are associated with a non-contact mechanism that involves a jump landing, cutting or pivoting maneuver (Agel, Arendt et al. 2005). Jump landing, cutting and pivoting maneuvers, without adequate neuromuscular control, have the potential to produce biomechanics that put the ACL at risk of rupture (Olsen, Myklebust et al. 2004). These high risk biomechanics include an increased external peak knee valgus moment, increased external peak hip internal rotation moment, and decreased internal knee flexion moment (Ireland 1999; Olsen, Myklebust et al. 2004; Boden, Torg et al. 2009; Hewett, Torg et al. 2009). During jump-landing or cutting with high risk landing patterns it is theorized that forces are such that the ACL may tear or rupture. In the healthy individual the primary function of the ACL is to prevent anterior tibial translation on the femur and resists proximal anterior tibial shear forces. In cadaveric models, strain on the ACL is at its greatest when the knee is near full extension with anterior tibial shear force applied to the shank (Hirokawa, Solomonow et al. 1992; Markolf, Burchfield et al. 1995). In this same model, if external valgus force was applied to the knee in conjunction with anterior shear force applied to the proximal tibia, there was increased strain on the ACL in flexion angles larger than 5 degrees (Markolf, Burchfield et al. 1995). Anterior tibial shear force in vivo is produced by quadriceps loading, which has been shown in several models (Hirokawa, Solomonow et al. 1992; Torzilli, Deng et al. 1994; Padua, Arnold et al. 2006; Sell, Ferris et al. 2007). Although the exact mechanisms that induce ACL injury are unknown, it can be inferred that in an intense sport activity instances may occur where forces are produced that are large enough to cause injury to the ACL.

Even after receiving ACL reconstructive surgery, there is evidence that long-term effects to lower extremity movement patterns exist. Paterno et al showed that even 2 years after surgery, “residual asymmetries with athletic maneuvers” persist (Paterno, Ford et al. 2007). In addition to being asymmetrical, changes in the kinematic profile of individuals after ACLR have been observed (Delahunt, Prendiville et al. 2012). Altered hip and knee joint kinematics were observed during a diagonal jump test by Delahunt et. al in female ACLR individuals that were cleared for full sport participation. This suggests that even after full return to sport risk factors for ACL injury still exist (Delahunt, Prendiville et al. 2012).

Residual proprioceptive deficits after ACLR may account for increased risk for ACL injury, as it has been observed that postural stability (sway velocity) is significantly different in ACLR individuals compared to healthy individuals (Zouita Ben Moussa, Zouita et al. 2009). A prospective study by Paterno et al 2010 found that individuals who demonstrated deficits in single-leg postural stability in the involved limb compared to the uninvolved limb were twice as likely to incur a second ACL injury (Paterno, Schmitt et al. 2010). Residual postural stability deficits, as well as limb asymmetries may increase an individual's risk for a second ACL injury (Zouita Ben Moussa, Zouita et al. 2009; Paterno, Schmitt et al. 2010).

Fatiguing exercise has been shown to produce changes in lower extremity biomechanics (Benjaminse, Habu et al. 2008). Fatiguing exercise, or muscular fatigue, is defined as any exercise-induced reduction in the ability of a muscle to generate force or power (Gandevia 2001). Muscular fatigue is a complex process that involves both peripheral changes within the muscle tissue itself, and also central changes, or changes in the neural drive to the muscle (Gandevia 2001). Fatigue has been observed to produce altered neuromuscular control strategies in jumping or cutting maneuvers (Chappell, Herman et al. 2005; Padua, Arnold et al. 2006; McLean, Fellin et al. 2007; Benjaminse, Habu et al. 2008). If an individual possesses asymmetries in lower extremity kinematics, fatiguing exercise could exacerbate these differences between limbs. The fatigue-altered control strategies have been suggested to contribute to non-contact ACL injuries (Chappell, Herman et al. 2005; McLean, Fellin et al. 2007; Benjaminse, Habu et al. 2008).

In the body of literature surrounding biomechanical and balance factors and ACL injury, there are several gaps considering muscular fatigue and its effect on ACLR individuals. A study by Webster et. al. suggested a change in lower extremity biomechanics in male ACLR individuals after fatiguing exercise (Webster, Santamaria et al. 2012). In this study, while several variables including lower extremity joint angles and external joint moments were collected, how these same individuals balance while fatigue was not investigated. Understanding how fatigue affects ACLR individuals can help sports medicine professionals make return to play decisions based on biomechanical analysis. Simple tasks like jump landing and single leg balance tests can be useful and easy to administer clinical tools that can evaluate the effect of fatigue on ACLR athletes.

Of the individuals who undergo ACL reconstruction (ACLR), the likelihood of sustaining a second ACL injury to either the reconstructed knee or contralateral knee has been reported to range from 6 to more than 20% (Salmon, Russell et al. 2005; Wright, Dunn et al. 2007; Shelbourne, Gray et al. 2009). These ACL injury prone individuals may possess specific neuromechanical factors that are different than individuals who never injure their ACL.

The purpose of this study is to investigate how fatigue affects lower extremity mechanics and balance in ACLR individuals. By fatiguing study participants who have undergone ACLR we hope to describe the specific biomechanical and balance changes that occur in these individuals that pre-disposes them to ACL injury. A better understanding of what makes ACLR individuals prone to injury can lead to better-designed rehabilitation protocol to prevent subsequent injury.

RESEARCH QUESTIONS

1. Do those with a prior ACL injury and ACLR respond differently to lower extremity muscle fatigue during a double leg jump landing as compared to those with no history of injury?
2. Do those with a prior ACL injury and ACLR respond differently to lower extremity muscle fatigue during single leg balance as compared to those with no history of injury?
3. Do those with a prior ACL injury and ACLR display differences in time to achieve muscular fatigue as compared with those with no history of injury?
4. Is there a difference between the ACLR limb and the non-injured limb in jump landing and balance tasks?

INDEPENDENT AND DEPENDENT VARIABLES

1. Independent Variables
    a. Group
        i. Healthy (Control)
        ii. ACLR
    b. Fatigue status
        i. Pre-fatigue
        ii. Post-fatigue
2. Dependent Variables
    a. Lower Extremity Biomechanical Measures
        i. Kinetic measures
            1. Hip and knee flexion angle at initial ground contact (IC)

2. Peak hip flexion angles
3. Peak knee flexion angle

ii. Kinematic measures

1. Peak external knee valgus moment
2. Peak external knee flexion moment
3. Peak medial tibial rotation moment
4. Peak lateral tibial rotation moment
5. Peak anterior tibial shear force (ATSF)
6. Peak vertical ground reaction force (GRF) in loading phase

b. Balance Measures

i. Average center of pressure sway velocity (COPv)

ii. Average center of pressure sway area (COPa)

c. Time to fatigue

i. Time in minutes (min)

RESEARCH HYPOTHESES

1. Participants will display altered lower extremity biomechanics and balance following the fatigue protocol as compared to pre-fatigue measures.
2. Fatigue will have a detrimental effect on lower extremity biomechanics by producing a kinematic profile consistent with increased risk of ACL injury.

OPERATIONAL DEFINITIONS

1. Muscular Fatigue: reduction in the maximum force generating capacity of muscle that is not due to pathological reasons.

2. Loading Phase: the period of time between initial ground contact and when the participant's knee flexion is at the smallest angle (thigh relative to the shank) in a jump-landing task.
3. Fatigue: the time when participants fall four squat cycles behind the set pace of 50 squat cycles per minute or failure to complete two consecutive squat cycles with a bar weighted to 1/3 of the participants' weight.

ASSUMPTIONS

1. The fatigue protocol produces adequate and equal fatigue for all participants for the duration of the tasks in which biomechanical data is recorded.
2. All participants in the ACLR group have received adequate rehabilitation to return them to full sport participation status.

LIMITATIONS

1. Participants may be unfamiliar with some of the tasks in the functional fatigue while others have some experience with the movements.
2. Participants may have prior experience with balance training.
3. Participants may have had different rehabilitation protocol and therapeutic exercise.
4. Participants may have undergone different ACL surgical procedures that use different graft procedures.

DELIMITATIONS

1. A physician has cleared all participants for sport participation.
2. All participants must exercise a minimum of 30 minutes at least 3 times a week.

3. No lower extremity injury that has made subjects unable to participate in regular exercise in the past 6 months.

SIGNIFICANCE

Epidemiological evidence of individuals who have a history of ACL reconstruction suggests that they are at an increased risk of incurring a second ACL injury to either limb (Myklebust, Holm et al. 2003; Paterno, Ford et al. 2007; Wright, Dunn et al. 2007; Shelbourne, Gray et al. 2009). While fatigue has been suggested to change lower extremity biomechanics and balance, the effect of fatigue on ACLR individuals lower extremity biomechanics and balance has yet to be investigated. By understanding how both injury status and fatigue effect lower extremity biomechanics and balance, safer decisions for return to play can be made by understanding the ACLR kinematic profile.

CHAPTER II

REVIEW OF THE LITERATURE

INTRODUCTION

The purpose of this literature review is to detail the body of evidence that exists regarding individuals who have undergone anterior cruciate ligament reconstruction (ACLR) and how these individuals may respond to fatigue. While fatigue has been investigated extensively and has been attributed to change in lower extremity biomechanics and balance, it has yet to be investigated the effect of fatigue on ACLR individuals' balance and lower extremity biomechanics This literature review will focus on the re-injury rate of ACLR individuals, kinematic and kinetic differences of ACLR individuals and healthy individuals, fatigue, fatigue and kinematics, fatigue and balance, and how fatigue may affect ACLR individuals.

The most common injury diagnosis to the knee is that of internal knee trauma (Majewski, Susanne et al. 2006). Internal knee trauma is defined as lesion to any of the internal knee structures including the collateral ligaments (ACL, PCL, LCL, MCL, medial meniscus and lateral meniscus). About 45% of all knee injuries are classified as internal knee trauma, with 45% of internal knee trauma cases including damage to the ACL (Majewski, Susanne et al. 2006). The highest incidence of ACL injuries occurs between the ages of 20 and 29, possibly reflecting the population of most physically active individuals (Majewski, Susanne et al. 2006).

ACL deficiency results in gross joint instability. This instability is responsible for causing pain, apprehension, and potential damage to other knee structures. The best treatment for the resulting gross instability from ACL injury is through surgical reconstruction. After surgical reconstruction, the prognosis for sport and long-term outcomes are moderate to poor (Ferretti, Conteduca et al. 1991; Myklebust, Holm et al. 2003). Less than one half of surgically reconstructed patients return to their original level of sport play when surveyed 2 to 7 years after reconstructive surgery (Ardern, Taylor et al. 2012). Of those who do return, around 40% later developed osteoarthritis (Myklebust, Holm et al. 2003). Injury to the anterior cruciate ligament (ACL) is a devastating and potentially career ending injury for an athlete as it has long term joint health and functional implications.

Injury reports and video analysis of ACL injuries have been used to describe lower extremity movement patterns of non-contact ACL injuries (Olsen, Myklebust et al. 2004; Boden, Torg et al. 2009; Hewett, Torg et al. 2009). The specific pattern includes as a trunk forward flexed and rotated to the opposite side, hips adducted, internally rotated, smaller flexion angles, valgus collapse of the knee, external tibial rotation, and weight forward on the balls of the feet(Ireland 1999; Myklebust, Holm et al. 2003; Olsen, Myklebust et al. 2004; Boden, Torg et al. 2009; Hewett, Torg et al. 2009). This posture is associated with a deceleration type movement representative of cutting, jumping, stopping or pivoting at the time of injury. Knee valgus moment is more sensitive to changes in hip rotation and abduction, so a combination of landing with a more lateral trunk motion, higher GRFv (Hewett, Torg et al. 2009; McLean and Beaulieu 2010).

In sport, this biomechanically hazardous position most often occurs during a "plant and cut" style change of direction or a single leg landing from a jump (Olsen, Myklebust et al. 2004). Alternatively, it has also been shown from video analysis that individuals sustaining a non-contact ACL injury exhibit a more “flatfooted” landing and more hip flexion than those that did not (Boden, Torg et al. 2009). Ireland et al describes a “position of no return”, with the back flexed forward and rotated to the opposite side of the limb, the hips adducted and internally rotated, the knee less flexed and in a valgus position, the tibia externally rotated with one foot turned “out of control” and weight forward on the balls of the feet (Ireland 1999). This is in direct opposition to Ireland’s described “position of safety”, which has the back with normal lordosis, hips flexed and with neutral adduction and rotation, knees flexed, tibias neutral with feet in “in control” and weight is centered over the center of the foot (Ireland 1999). The “position of no return” has the lower extremity muscle groups at a mechanical disadvantage due to their altered length-tension relation, making biomechanical correction difficult in this dangerous position (Ireland 1999).

KINEMATIC AND KINETIC DIFFERENCES BETWEEN ACLR INDIVIDUALS AND HEALTHY INDIVIDUALS

Recently there have been several studies documenting the differences in movement patterns and balance in ACLR individuals and healthy individuals. A study by Paterno et al found that female athletes had increased peak vertical ground reaction force (GRFv) and loading rate in the contralateral limb, and higher GRFv than controls (Paterno, Ford et al. 2007). High GRFv is usually accompanied by a more erect landing posture with less flexion at the hip and knee; this makes the lower extremity unable to attenuate the impulse of the landing over such a short period of time. This landing posture is associated with increased anterior shear forces on the ACL (Kanamori, Woo et al. 2000).

Hip transverse plane moment impulse is suggested to be the one of the strongest predictors of a second ACL injury in ACLR individuals (Paterno, Schmitt et al. 2010). Individuals who displayed less hip external rotation moment in the early landing phase were more than 8 times as likely to sustain a second ACL injury than individuals with a greater hip external rotation moment (Paterno, Schmitt et al. 2010). Individuals who sustained a second ACL injury also displayed a higher angular displacement of the knee in the frontal plane (typically described as knee valgus), and were over three times as likely to acquire a second ACL injury than those with reduced displacement (Paterno, Schmitt et al. 2010).

Asymmetries in ACLR individuals are also seen between the knee extensor moment of the involved and uninvolved knees. Individuals who sustained a second ACL injury had an over 4 fold greater asymmetry in knee extensor moments at initial contact when landing from a jump (Paterno, Schmitt et al. 2010). Paterno et al found that the uninvolved knee displayed an internal knee extensor moment that was significantly lower at initial contact compared to the involved limb in the second injury group (Paterno, Schmitt et al. 2010).

Clinically, single leg balance is often used as a functional assessment of postural stability following ACLR. It has been found that even two years after ACLR there are postural stability deficits, indicating a persisting deficiency in proprioception (Zouita Ben Moussa, Zouita et al. 2009). In a prospective study by Paterno et al 2010 deficits were found in postural stability in the ACLR limb (Paterno, Schmitt et al. 2010). The individuals who exhibited greater postural stability deficits in the injured limb (as compared to the uninvolved limb) were two times as likely to withstand a second ACL injury (Paterno, Schmitt et al. 2010).

FATIGUE

A known factor that affects lower extremity movement patterns is muscular fatigue. Most sports, including those who have a high instance of ACL injury such as soccer or basketball, involve the repetitive contraction of large muscle groups over an extended period of time producing muscular fatigue. The processes that produce muscular fatigue are complex and involve several body systems.

The two main components that comprise muscular fatigue are central fatigue and peripheral fatigue. Central fatigue involves all processes proximal from the neuromuscular junction to the central nervous system. This involves submaximal output from the motor and premotor areas of the cortex, resulting in a decrease in neural drive to the motor unit (Gandevia, Allen et al. 1996). Peripheral fatigue is a process of the failure of systems distal to the neuromuscular junction resulting in a decrease in force production (Kirkendall 1990). This includes ion depletion in the sarcolemma, calcium depletion in the sarcoplasmic reticulum, decreased availability of ATP for cross-bridge formation and decrease in relative stores of blood glucose and muscle glycogen (Kirkendall 1990).When athletes participate in sports they experience muscular fatigue as they perform dynamic movements, and over time muscular fatigue can degrade performance by producing deficits in movement patterns and postural control.

Traditionally, fatigue is defined as the time-dependent decrease in the force producing capability of muscle not due to pathological reasons (Gandevia, Allen et al. 1996). Many researchers utilize the maximum volume of oxygen consumption (VO_2 Max) to measure when a subject is considered fatigued. If you know a person's VO_2 Max, then theoretically you know that individual will be unable to continue exercising beyond an intensity that requires a higher level of oxygen to fuel the muscles. In the absence of oxygen muscles must produce lactic acid to make ATP. Lactic acid has long since been thought of as a limiting factor in exercise because it impairs muscles ability to function (Noakes 2008). Therefore, when muscles no longer have oxygen, their force producing capability is reduced and a fatigue state is reached.

Recently it has been suggested that determining when an individual is fatigued may not be so simple. Many exercise physiologists use blood lactate levels to measure fatigue during exercise. Being able to determine a persons fatigue level by blood lactate levels may be inaccurate because there is a large variability in blood lactate levels for the same exercise intensity for individuals (Morton, Stannard et al. 2012). Another classic measure of fatigue is a rate of perceived exertion (RPE) scale, such as the Borg Scale (Borg 1970). The premise of a RPE scale is that both physiological and psychological factors determine how a person reaches a fatigued state. A recent study by Pires et al saught to determine if the physiological and psychological components of fatigue are independent of one another (Pires, Noakes et al. 2011). Pires did this by suggesting to participants that they were exercising at a lower intensity during one of two occasions, while in reality the intensity of exercise were identical in both trials. Although one would hypothesize that the trial when participants had been told they were exercising at a lower intensity would report lower RPE scores, the scores for the two trials were the same (Pires, Noakes et al.

2011). Therefore RPE scale would be a fairly reliable measure of when an individual reaches fatigue.

FATIGUE: KINETICS AND KINEMATICS

There is extensive research that suggests that muscular fatigue produces altered neuromechanical movement patterns in healthy individuals. A study by Thomas et al 2010 found that isolated fatigue of the quadriceps and hamstring muscles produced higher hip internal rotation, knee extension and knee external rotation at initial contact during a single leg hop task as compared to pre-fatigue measurements (Thomas, McLean et al. 2010). This increased the joint loading post fatigue, potentially putting the ACL at increased risk of injury. Valgus movement at the knee (associated with ACL injury mechanisms) is produced by a combination of hip internal rotation, flexion, adduction, and tibial external rotation(Chappell, Herman et al. 2005; Palmieri-Smith, McLean et al. 2009; McLean and Beaulieu 2010; Thomas, McLean et al. 2010). Fatigue also increases varus/valgus moment from pre-fatigue measurements of jump landing tasks (Chappell, Herman et al. 2005).

After bouts of fatiguing running it has been shown that during a single leg jump landing task subjects tend to land in less knee flexion (Benjaminse, Habu et al. 2008). Although this stiff landing pattern may be a protective strategy to prevent excessive knee valgus load and eccentric hamstring activation, landing in more extension puts the most stress on the ACL especially when pivoting (Kanamori, Woo et al. 2000; Padua, Arnold et al. 2006). The stiff landing strategy puts more reliance on the static structures in the knee, as the dynamic structures can no longer maintain adequate force output to maintain knee stability (Benjaminse, Habu et al. 2008). The static restraint for anterior tibial translation and external rotation (in a pivot type maneuver) is the ACL. Therefore when the lower extremity is fatigued and utilizing a stiff landing strategy, the ACL is at increased risk of injury (Padua, Arnold et al. 2006; Benjaminse, Habu et al. 2008).

The stiff landing strategy has also been described as a "quadriceps dominant" strategy as the quadriceps display increased activation coupled by a decrease in hamstring activation(Padua, Arnold et al. 2006; Zebis, Bencke et al. 2010). Because the hamstrings are the primary agonists to the ACL for anterior translation, their decreased force output and the increased quadriceps force create an anterior tibial shear force (Padua, Arnold et al. 2006; Zebis, Bencke et al. 2010). After fatigue the lower extremity musculature tends to rely on more non-fatigued muscle groups to maintain stability, in particular the gastrocnemius-soleus complex (Bonnard, Sirin et al. 1994). This is considered an "ankle strategy" to regulate total vertical leg stiffness (Padua, Arnold et al. 2006).. Due to the line of pull, the gastrocnemius acts as an antagonist to the ACL (Fleming, Renstrom et al. 2001). Increased gastrocnemius activation without changes in hamstring activation (as in the fatigued state) help to decrease the strain on the ACL in an "ankle strategy"(Fleming, Renstrom et al. 2001; Padua, Arnold et al. 2006). The combination of fatigue and cutting and jump landing movements push kinematics towards the "position of no return" and increases the risk of non-contact ACL injury (Ireland 1999; McLean, Fellin et al. 2007).

FATIGUE AND BALANCE

Fatigue has also been suggested to produce deficits in balance, or postural control(Corbeil, Blouin et al. 2003; Gribble and Hertel 2004; Wilkins, Valovich McLeod et al. 2004; Yaggie 2004). During normal, non-fatigued quiet stance, small muscular corrections in the lower extremity are made in response to directional changes in body mass to maintain an upright posture. Good postural control is the body's ability to adequately correct for these deviations, maintain balance, and keep the center of pressure within the base of support. In the fatigued state postural control is negatively affected because of suboptimal neural drive from the central nervous system, and therefore inadequate muscular corrections to postural sway (Gandevia, Allen et al. 1996; Gribble and Hertel 2004). This creates greater changes in joint motion while in quiet standing, and poorer postural control (Gribble and Hertel 2004). Performance on the Balance Error Scoring System, a clinical tool used to assess postural control, has shown to be negatively affected by fatigue (Wilkins, Valovich McLeod et al. 2004). This represents an increase in the number of balance errors due to fatigue, and the inability to maintain postural control.

Fatigue in the lower extremity can affect postural stability greater the more proximal the fatigued muscle groups exist (Gribble and Hertel 2004). Fatigue at the hip and knee affects medial and lateral postural stability more than localized fatigue at the ankle in static stance (Gribble and Hertel 2004). This could be because the muscles at the hip and knee are much larger than at the ankle, and are less able to produce finer adjustments in posture because of an increased recruitment of motor units to maintain force output when fatigued (Gribble and Hertel 2004). Research has also found that fatigue has a greater effect on the muscular component of postural control than the sensory system, or vision (Corbeil, Blouin et al. 2003). The frequency of muscular corrections for changes in sway greatly increases post fatigue, with changes in sensory input occurring at the peripheral level (Corbeil, Blouin et al. 2003).

FATIGUE AND ACLR INDIVIDUALS

A limitation in current ACL research is identifying how fatigue affects the movement patterns in ACLR individuals. The most significant risk factor for contralateral ACL injury was return to sports that involve cutting, jumping or pivoting (Salmon, Russell et al. 2005). The nature of these types of sports (like soccer and basketball) involves game play that produces fatigue. Research has shown that fatigue predisposes healthy individuals to hazardous movement patterns and balance deficits, but it is not yet known how fatigue affects ACLR individuals who already display altered movement patterns and deficits in balance. Investigating the role of fatigue on lower extremity movement patterns and balance in ACLR individuals may provide a more accurate view on how successive ACL injuries manifest.

Both fatigue and ACLR have effects on balance, but the interaction of the two have yet to be investigated(Corbeil, Blouin et al. 2003; Gribble and Hertel 2004; Wilkins, Valovich McLeod et al. 2004; Yaggie 2004; Paterno, Ford et al. 2007). A measure of dynamic balance is "time to stabilization", or the time to stabilize after a single leg jump landing (Webster and Gribble 2010; Webster, Santamaria et al. 2012)This measurement of postural control best mimics a functional task that athletes perform during jumping or cutting sports, and is a good indicator of neuromuscular control. Webster et al found that

ACLR individuals took significantly longer to stabilize after jump landing than healthy individuals performing the same task (Webster and Gribble 2010; Webster, Santamaria et al. 2012). Even division 1 female athletes with an average of 2.5 years post ACLR take significantly longer time to stabilization than that of a healthy population (Webster, Santamaria et al. 2012). This indicates long-term lingering deficits in neuromuscular control for ACLR individuals. If ACLR individuals suggest neuromuscular control deficits in the non-fatigued state, these deficits have the potential to be exacerbated under fatigued conditions.

Considering the motion analysis variables in previous fatigue studies that best indicate the propensity for producing hazardous movement patterns, there are several that were consistently different pre to post fatigue during a jump-landing task. The most notable that could potentially increase strain on the ACL were: knee flexion angle decrease from pre to post fatigue, hip internal rotation increase pre to post fatigue, and hip adduction and flexion increase pre to post fatigue (Chappell, Herman et al. 2005; Padua, Arnold et al. 2006; Benjaminse, Habu et al. 2008; Thomas, McLean et al. 2010).

RE-INJURY RATE FOR ACLR INDIVIDUALS

Even further complicating the prognosis of individuals who have undergone ACLR is the instance of re-injury to the reconstructed ACL, as well as the ACL in the contralateral knee(Myklebust, Holm et al. 2003; Paterno, Ford et al. 2007; Wright, Dunn et al. 2007; Shelbourne, Gray et al. 2009; Paterno, Rauh et al. 2012). In a study by Paterno et al, individuals that had previous history of ACLR are 15 times at greater risk to incur a second injury as compared to a healthy population (Paterno, Rauh et al. 2012). In particular, female athletes had a second ACL injury rate of 16 times that of healthy female controls (Paterno, Rauh et al. 2012). Females also had a re-injury rate that was 4 times that of the re-injury rate of male ACLR participants (Paterno, Rauh et al. 2012). These results are very concerning of clinicians and sport staff served with the duty of rehabilitation of these ACL injured athletes.

Analyzing kinematic, kinetic and postural stability measures on ACLR individuals in the fatigued state will describe the movement profile of ACLR individuals under exercise conditions. The high incidence of ACL injury among all people with knee injuries, as well as the biomechanical and balance changes that occur within these individuals after the initial injury indicate that there are residual deficits that persist long after the ligament has been repaired. By successfully identifying which individuals have asymmetrical landing biomechanics, intervention may be able to be applied to help prevent successive injuries to the ACL. The effect of fatigue will be particularly valuable to develop a profile of how these ACLR individuals differ from healthy individuals. From this data, we can construct different return to play criteria as well as criteria to screen for deficits within ACLR individuals, hopefully preventing future ACL injury.

CHAPTER III

METHODOLOGY

PARTICIPANTS

This study was a pre-experimental pre-test, post-test design with all participants belonging to an ACLR group. A total of 17 ACLR participants were used in this study.. Based on previous fatigue studies on lower extremity landing biomechanics, a priori power analysis requires a minimum of 10 subjects to achieve a power of 0.8 (Webster, Santamaria et al. 2012).. Non-random assignment of ACLR participants were used as they were selected with specific inclusion criteria. Participants were selected from students at the University of North Carolina at Chapel Hill and the geographical area around the university.

INCLUSION CRITERIA FOR PARTICIPATION

- Participants exercise for at least 30 min, at least 3 times a week
- Participants are between the ages of 18 and 30 years old
- Participants are female.

EXCLUSION CRITERIA FOR PARTICIPATION

- Participants that are not cleared by their physician to participate in exercise.
- Participants with a history of bilateral ACL injury or injury to the MCL, PCL, LCL or meniscus in the contralateral knee.

- Participants are more than 6 years post ACLR.
- Participants who have had any lower extremity injury episodes in the past 6 months that has left them unable to participate in physical activity for more than 3 consecutive days.
- Participants with a history of more than one ACL injury.

INSTRUMENTATION

Kinematic Data Collection

An electromagnetic motion tracking system (Flock of Birds; Ascension Technologies Inc, Burlington VT) was used to record kinematic data. All kinematic data were recorded at a sampling frequency of 1400Hz (Bennett, Blackburn et al. 2008).

Kinetic Data Collection

A non-conductive force plate (Type 4060-08 Bertec Corporation, Worthingtion, OH) was used to collect all kinetic variables of interest. Ground reaction force data were sampled at 1,400 Hz.

PROCEDURES

All participants reported for a single testing session for data collection, lasting approximately 1.5 hours. Before participating in the study all participants read and signed an informed consent approved by the institutional review board for the University of North Carolina at Chapel Hill (Appendix A). All participants also completed an active population questionnaire (Appendix B) and a physical activity readiness questionnaire

(PAR-Q) (Appendix C)(Shephard 1988). To ascertain ACL injury and surgical history, a questionnaire was given (Appendix D). The Marx scale, a questionnaire that details the amount of running, cutting, deceleration and pivoting the participant performs within a month, was also completed by the participant (Appendix E)(Marx, Stump et al. 2001). To determine post-surgical knee functional outcomes the participants were given a Knee Injury and Osteoarthritis Outcome Scale (KOOS) questionnaire (Appendix F) (Roos and Lohmander 2003). In addition a Tegner Activity Scale questionnaire was given to the participants to assess activity level before and after surgery (Appendix G) (Hambly 2011). Participant's height and mass was measured with a stadiometer and digital scale, and was recorded prior to collection of biomechanical data. Each participant performed a 5 minute light stationary bike warm up followed by 5 min of light stretching. Immediately after warm-up, electromagnetic sensors were attached to the shank and thigh of both legs as well as the sacrum using double-sided tape, a Velcro belt and secured with pre-wrap and athletic tape. The shank segment was digitized using a movable sensor, indicating the medial and lateral femoral epicondyles, medial and lateral malleoli and right and left anterior superior iliac spine. After the participants were digitized, testing protocol began.

A global axis system was defined based on a right-hand coordinate system with the positive x-axis corresponding with the anterior direction, positive y-axis corresponding with the lateral direction, and positive z-axis corresponding with superior direction. Local coordinate systems for the shank, thigh, and pelvis segments will correspond with that of the global axis system. The ankle joint center was defined as the midpoint between the medial and lateral malleolus, knee joint center as the midpoint between the medial and lateral femoral epicondyle, and hip joint center estimated from the right and left anterior superior iliac spine using the Bell Method (Bell, Pedersen et al. 1990). The three non-colinear points of the ankle joint center, knee joint center, and shank sensor defined the shank segment. The thigh segment was defined by the knee joint center, hip joint center and thigh sensor. The pelvis was defined by the left anterior superior iliac spine, right anterior superior iliac spine and sacrum sensor.

Joint motion at the knee was defined as the motion of the shank segment relative to the thigh segment using an Euler sequence of Y, X', Z''; with sagittal plane motion (+ flexion, - extension) defined about the Y-axis, frontal plane motion (+ varus, - valgus) defined about the X-axis, and transverse plane motion (+ internal rotation, - external rotation) defined about the Z-axis.

Double Leg Jump Landing

The jump-landing task was preformed with a 30cm box placed at a distance equal to half the participants' height from the leading edge of the force plate. Participants were instructed to jump from the box to the force plate, landing with two feet. Then upon landing, participants were instructed to jump as high as possible (Myer, Ford et al. 2006; Padua, Arnold et al. 2006). A successful jump landing trial is only when the participant had landed two feet and with the specified foot (left or right) on the force plate. Participants were allowed 3 practice jumps to familiarize themselves with the task. A total of 10 successful trials were collected, 5 with the right leg landing on the force plate and 5 with the left leg landing on the force plate.

Single Leg Balance Test

Participants completed a single leg balance test on the force plate to assess balance. After they had removed their shoes from the jump landing task, each participant completed the single leg balance test with eyes closed while standing on the center of the force plate, trying to stand as still as possible. Participants were instructed to place hands on hips for the duration of the balance task. Each participant balanced on a single leg for 20 seconds while COP data were collected. Trials were repeated if the participant touched down with the non-stance foot, took hands off their hips, or opened their eyes. A total of 6 successful trials were collected, 3 while standing on the right foot and 3 while standing on the left foot.

Fatigue Protocol

The fatigue protocol was adopted from a similar study by Padua et. all (Padua, Arnold et al. 2006). Participants performed repeated squatting motions with the weighted bar through a knee flexion range of 0° to 60°. The bar for each participant was weighted to approximately 30% of the participants' mass in pounds. Knee range of motion during the fatigue protocol was controlled as participants were instructed to come to a knee extended position (0°) when moving upwards then lightly touch the end range of motion block (adjustable tripod) that was set at 60° of knee flexion when moving downwards. Frequency of the squatting motion during the fatigue protocol was controlled using the beat of a digital metronome as subjects perform repeated weighted squats at a frequency of 50 beats per minute. Each beat represented the beginning and bottom of each squat during the squat cycle. One squat cycle was defined as the period of time when the participant moved from an upright standing position (0° knee flexion) to the squatting position (60° knee flexion), and back to the upright standing position (two beats of the digital metronome). Participants were instructed to maintain a constant rate of movement for both the downward and upward motion of the squat. The relative loading and movement frequency had been selected from pilot testing.

The fatiguing exercise was terminated when participants fell four squat cycles behind the 50 squats per minute set pace or failed to complete two sequential squat cycles. The need to come into full knee extension and lightly touch the range of motion block when moving into knee flexion, even at the cost of falling behind the set cadence was emphasized to the subjects in order to maintain a constant, even motion. Participants continued to exercise until verbally instructed to stop when the investigator had observed that they met stop criteria. After stop criteria was met, the participant reported a Borg perceived rate of exertion rating (print out was given to the participant to circle the appropriate rating immediately after terminating the fatigue protocol) (Borg 1970).

DATA REDUCTION

All data was recorded using the Motion Monitor Software version 9 (Innovative Sports Technology, Chicago, IL), exported from Motion Monitor, and then reduced using Matlab Software (2011 The MathWorks, Inc.).

DATA ANALYSIS

The kinematic variables of interest were collected during the jump-landing task and include: hip and knee flexion angle at IC, peak hip and knee flexion angles, peak external knee valgus moment, peak external knee flexion moment, peak tibial rotation moment, peak ATSF, peak GRF. IC was defined as the first 10 miliseconds after the participant had landed on the force plate. Kinetic variables of interest that were collected during the balance trials include average COPv and average COPa. An a priori alpha level for this study was set at $\alpha = 0.05$. A 2 × 1 mixed-model analysis of variance was conducted for each kinematic and kinetic variable. All variables were analyzed on the levels of pre-fatigue and post-fatigue. **A** Tukey post hoc analysis was run to determine which means were significantly different. We are particularly interested in the interaction effects of fatigue status across all variables due to the lack of evidence to support that fatigue factors into incurring a second ACL injury. All statistical analyses were performed using SPSS 19.0.

APPENDIX A

University of North Carolina-Chapel Hill
Information about a Research Study

IRB Study #: **Consent Form Version Date:** 1/16/2012

Title of Study: The Effect of Fatigue on Lower Extremity Biomechanics and Balance between ACLR and Healthy Individuals

Principal Investigator: Christine Gilsdorf
UNC-Chapel Hill Department: Exercise and Sport Science
Faculty Advisor: Darin Padua, PhD ATC

Study Contact telephone number: 919-843-9674
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<u>What are some general things you should know about research studies?</u>
You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

<u>What is the Purpose of this study?</u>
We want to understand how people who have had anterior cruciate ligament reconstruction (ACLR) move differently from people that have not had the surgery. Previous research suggests that individuals who have had ACLR are more likely to have another anterior cruciate ligament (ACL) injury. We want to learn how ACLR individuals jump and balance, so see if movement patterns exist that makes these people more prone to injure their ACL.

<u>Are there any reasons you should not be in this study?</u>

You should not participate in this study if you have had more than one ACL injury, if you have ever injured your meniscus, or have injured your medial collateral ligament (MCL). You should not participate in this study if you have had an injury in the past 6 months that has left you unable to exercise for at least 3 consecutive days. <u>You should not participate in this study if, after recovery from ACLR, your physician has not cleared you to engage in exercise.</u>

<u>How many people will take part in this study?</u>
If you decide to be in this research study, you will be one of approximately 40 people to participate.

<u>How long will your part in this study last?</u>
You will be asked to report for one session lasting approximately 2 hours.

<u>What will happen if you take part in the study?</u>
After you fill out this consent form and physical readiness questionnaire (PAR-Q), then you will be eligible to participate in All participants groups will report on a single occasion for data collection, lasting approximately 2 hours. You should come dressed in light athletic clothing and running shoes. Height and weight will be measured and recorded prior to the start of the study. You will be required 5 minutes of light stationary bike warm up at a speed and intensity of your choosing, which will be followed by 5 minutes of light stretching. Immediately after warm-up testing protocol will begin.

You will be outfitted with electromagnetic sensors to your thigh, lower leg, and sacrum. These sensors will be secured with double sided tape, pre-wrap and athletic tape. This will be digitized so a 3D model of your lower extremity can be made by the computer.

Jump Landing Followed by Maximum Height Jump
You will be asked to perform a jump landing and maximum height jump while outfitted with the electromagnetic sensors. From a box, you will have to jump onto a force-plate on the floor then jump as high as you can. You will be allowed 3 practice jumps before we record data. We will collect data from 3 jumps before and 3 jumps after the fatigue protocol.

Single Leg Balance Test
You will be asked to balance on a single leg on the force-plate with your eyes open for 20 seconds. While you balance you will need to keep your hands on your hips and keep your non-stance foot in the air. You will be allowed 1 20-second practice trial. Once you believe you have found your balance you will alert the investigator and your balance trial will begin. You will complete 3 balance trials before and 3 balance trials after the fatigue protocol.

Fatigue Protocol
The fatigue protocol will be administered after the initial jump landing and single leg balance tests. A 5-minute rest period will be permitted after the initial testing of the jump-

landing and balance tasks. The fatigue protocol will consist of a continuous squatting task with a bar weighted to 30% of your weight. You will be asked to squat in time with a metronome. We will alert you when stop criteria is met and you can end the fatigue protocol. After the fatigue protocol is stopped, the second set of jump landing and balance tasks will be administered. A booster fatigue protocol will also be administered in between the second set of jump landing and balance tasks. This booster fatigue will have the same protocol as the initial fatigue protocol, and is designed to make sure you remain fatigued for the second task.

<u>What are the possible benefits from being in this study?</u>
You will not benefit personally from being in this research study.

<u>What are the possible risks or discomforts involved with being in this study?</u>
As with any physical activity, participation in this study carries a risk of bodily injury. The motions that you will be asked to perform are ones that repeatedly occur during physical activity. Therefore, you should be familiar and able to perform the tasks with minimal injury risk. To further minimize injury risk, you will be allowed to warm up and stretch to prepare for testing. <u>You may experience discomfort associated with intense physical exercise, which may include shortness of breath, muscle camping and fatigue. Any physical discomfort should cease shortly upon ending the fatigue protocol. Some lasting mild muscle soreness may persist for several minutes to days after completion of the protocol. Some muscle soreness (comparable to that experienced after an intense bout of exercise) may last for several minutes to days after the protocol.</u>

<u>If you have had ACLR, you may be at increased risk for re-injury compared to the general population. You are only allowed to participate in this study if you have been cleared by your physician to participate in exercise after ACLR.</u>

In case of injury, medical personnel (certified athletic trainers) will be located in building adjacent to the testing session. You are free to stop participation at any time.

In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

<u>What if we learn about new findings or information during the study?</u>
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

<u>How will your privacy be protected?</u>
No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the

University, research sponsors, or government agencies for purposes such as quality control or safety.

All data collected will be stored in computers that are locked in the Sports Medicine Research Laboratory at all times. Only investigators involved in the study will have access to this data on a need basis. All data will be kept for 1 year, and will be discarded appropriately.

<u>What will happen if you are injured by this research?</u>

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

APPENDIX B

Active Population Questionnaire

1. What is your age? _____________ years old

2. How many days a week do you exercise? ______________________days

3. Of these exercise days, what is the average amount of time you spend exercising?
   __________________ mins
   Appendix A – Active Population Questionnaire

APPENDIX C

PAR-Q

Please read each question carefully and circle either YES or NO for each question. Common sense is your best guide when you answer these questions.

YES/NO	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
YES/NO	2. Do you feel pain in your chest when you do physical activity?
YES/NO	3. In the past month, have you had chest pain when you were not doing physical activity?
YES/NO	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
YES/NO	5. Do you have a bone or joint problem (for example, back knee or hip) that could be made worse by a change in your physical activity?
YES/NO	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
YES/NO	7. Do you know of any other reason why you should not do physical activity?

APPENDIX D

ACLR History Questionnaire

1. When was the date of your ACL injury? (To the closest month and year, for example: January 2009)____

2. How did you injure your ACL? (Example: cutting, jumping, collision with another player/object)____

3. When was the date of your ACL surgery? (to the closest month an year)____

4. Did you complete post-surgical rehabilitation after your surgery? When did you begin? (Express in weeks after surgery. If immediately after surgery write "immediately")__________________________________

5. When were you cleared to participate in physical exercise after your surgery? (To the closest month and year)____

6. What graft type did your surgeon use? (Example: hamstring, patellar tendon, Achilles tendon. If unknown write "N/A")________________________________

APPENDIX E

Marx Scale

Please indicate how often you performed each activity in your healthiest and most active state, in the past year.

Kindly put a (✓) mark on the appropriate space after each item.

	Less than one time in a month	One time in a month	One time in a week	2 or 3 times in a week	4 or more times in a week
Running: running while playing a sport or jogging					
Cutting: changing directions while running					
Deceleration: coming to a quick stop while running					
Pivoting: turning your body with your foot planted while playing sport; For example: skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash), etc.					

APPENDIX F

Knee Injury and Osteoarthritis Outcome Score (KOOS)

Source: Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS)--development of a self-administered outcome measure. *J Orthop Sports Phys Ther*. 1998 Aug;28(2):88-96.

The Knee Injury and Osteoarthritis Outcome Score (KOOS) is a questionnaire designed to assess short and long-term patient-relevant outcomes following knee injury. The KOOS is self-administered and assesses five outcomes: pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life. The KOOS meets basic criteria of outcome measures and can be used to evaluate the course of knee injury and treatment outcome. KOOS is patient-administered, the format is user-friendly and it takes about 10 minutes to fill out.

Scoring instructions

The KOOS's five patient-relevant dimensions are scored separately: Pain (nine items); Symptoms (seven items); ADL Function (17 items); Sport and Recreation Function (five items); Quality of Life (four items). A Likert scale is used and all items have five possible answer options scored from 0 (No problems) to 4 (Extreme problems) and each of the five scores is calculated as the sum of the items included.

Interpretation of scores

Scores are transformed to a 0–100 scale, with zero representing extreme knee problems and 100 representing no knee problems as common in orthopaedic scales and generic measures. Scores between 0 and 100 represent the percentage of total possible score achieved.

Knee Injury and Osteoarthritis Outcome Score (KOOS)

Pain

P1 How often is your knee painful?	☐ Never	☐ Monthly	☐ Weekly	☐ Daily	☐ Always

What degree of pain have you experienced the last week when ?

P2 Twisting/pivoting on your knee	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P3 Straightening knee fully	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P4 Bending knee fully	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P5 Walking on flat surface	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P6 Going up or down stairs	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P7 At night while in bed	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P8 Sitting or lying	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P9 Standing upright	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

Symptoms

Sy1 How severe is your knee stiffness after first wakening in the morning?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sy2 How severe is your knee stiffness after sitting, lying, or resting later in the day?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sy3 Do you have swelling in your knee?	☐ Never	☐ Rarely	☐ Sometimes	☐ Often	☐ Always
Sy4 Do you feel grinding, hear clicking or any other type of noise when your knee moves?	☐ Never	☐ Rarely	☐ Sometimes	☐ Often	☐ Always
Sy5 Does your knee catch or hang up when moving?	☐ Never	☐ Rarely	☐ Sometimes	☐ Often	☐ Always
Sy6 Can you straighten your knee fully?	☐ Always	☐ Often	☐ Sometimes	☐ Rarely	☐ Never
Sy7 Can you bend your knee fully?	☐ Always	☐ Often	☐ Sometimes	☐ Rarely	☐ Never

Activities of daily living

What difficulty have you experienced the last week ?

A1 Descending	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A2 Ascending stairs	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A3 Rising from sitting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A4 Standing	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A5 Bending to floor/picking up an object	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A6 Walking on flat surface	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A7 Getting in/out of car	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A8 Going shopping	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A9 Putting on socks/stockings	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A10 Rising from bed	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A11 Taking off socks/stockings	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A12 Lying in bed (turning over, maintaining knee position)	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A13 Getting in/out of bath	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A14 Sitting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A15 Getting on/off toilet	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A16 Heavy domestic duties (shovelling, scrubbing floors, etc)	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A17 Light domestic duties (cooking, dusting, etc)	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

Sport and recreation function

What difficulty have you experienced the last week ?

Sp1 Squatting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp2 Running	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp3 Jumping	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp4 Turning/twisting on your injured knee	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp5 Kneeling	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

Knee-related quality of life

Q1 How often are you aware of your knee problems?	☐ Never	☐ Monthly	☐ Weekly	☐ Daily	☐ Always
Q2 Have you modified your lifestyle to avoid potentially damaging activities to your knee?	☐ Not at all	☐ Mildly	☐ Moderately	☐ Severely	☐ Totally
Q3 How troubled are you with lack of confidence in your knee?	☐ Not at all	☐ Mildly	☐ Moderately	☐ Severely	☐ Totally
Q4 In general, how much difficulty do you have with your knee?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

APPENDIX G

Tegner Activity Scale

Please indicate in the spaces below the HIGHEST level of activity that you participated in BEFORE YOUR INJURY and the highest level you are able to participate in CURRENTLY.

BEFORE INJURY: level__________ CURRENTLY: level________________

Level 10	Competitive sports – soccer, football, rugby (national elite)
Level 9	Competitive sports – soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball
Level 8	Competitive sports – racquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing
Level 7	Competitive sports – tennis, running, motorcars speedway, handball Recreational sports – soccer, football, rugby, bandy ice hockey, basketball, squash, racquetball, running
Level 6	Recreational sports – tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times per week
Level 5	Work – heavy labor (construction etc.0 Competitive sports - cycling, cross-country skiing, Recreational sports – jogging on uneven ground at least twice weekly
Level 4	Work – moderately heavy labor (e.g. truck driving, etc.)
Level 3	Work – light labor (nursing, etc.)
Level 2	Work – light labor Walking on uneven ground possible, but impossible to back pack or hike
Level 1	Work – sedentary (secretarial, etc.)
Level 0	Sick leave or disability pension because of knee problems

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